The Effect of ENSO on the Intraseasonal Variance of Surface Temperatures In Winter

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Abstract:

The effect of the El Niño Southern Oscillation (ENSO) on the probability distribution of daily surface air temperature over the Pacific-NorthAmerican sector is investigated using NCEP Reanalysis data for 1959-1998. The El Niño response is characterized by reduced intraseasonal variance over most of the U.S., western Canada and the Gulf of Alaska. Conversely, there is an increase of variance relative to climatology during La Niña over the U.S. and the west coast northward to Alaska. The sign of this response is consistent for most individual El Niño/La Niña years in regions with a strong signal. The response is also robust with respect to differing definitions of ENSO or choice of dataset. Finally, a similar response is evident in station data for an earlier period. The change of variance is associated both with altered skewness and a change in high and low extremes. Extremes of both signs are reduced during El Niño, and are slightly increased during La Niña. These results are consistent with other studies suggesting an increased incidence of blocking along the west coast of North America during El Niño, leading to less storm activity and less incursions of warm and cold air over the eastern US. While an understanding of the changed variance is important in itself, it also has implications for changes in exceedence statistics (e.g. heating degree days) and the occurrence of extreme values.

1. Introduction

The relationship between ENSO events in the tropical Pacific and the seasonal mean surface temperature response over the globe has been extensively documented, both observationally (e.g. Ropelewski and Halpert 1986, Kiladas and Diaz 1989, Wolter et. al. 1999) and through model analyses (e.g. Lau 1985). While this response appears to be robust in many regions, the question remains of how ENSO affects the higher moments of the daily data distribution that make up the seasonal means. Distribution shifts can have important implications for extreme values. Mearns (1984) demonstrated that changes of variance have a strong effect on extreme values with or without accompanying changes of the mean. For ENSO conditions, one may ask if a change in the daily distribution of temperatures can be demonstrated, in addition to shifts in the mean. Earlier studies of geopotential heights and stormtrack variability (e.g. White 1989, Horel 1988, Harnack 1984, Nakamura 1996, Noel 1998) found that ENSO can affect intraseasonal variability in the Pacific North American region, primarily by affecting the incidence of blocking and deep trough formation over the Gulf of Alaska through interactions between synoptic eddies and the mean flow. While the relationship to air temperature should be similar to that of geopotential heights, correlations with daily data over land are only on order 0.25-.80 in winter so the distribution of air temperature may differ substantially from the distribution of heights. Because knowledge of surface air temperatures has practical applications in farming, energy use and other fields (e.g. Hansen 1995, Mote 1996) and because it is clear that detailed knowledge of the distribution would be useful (Downtown, 1993), a study of the effect of ENSO on these higher moments is warranted. In addition, higher intraseasonal variance may be responsible for decreased predictability (Dixon, 1986).

Earlier studies gauging the impact of ENSO on temperature variance have either been regional in nature (Plummer 1996, Rogers 1988) or concerned with the effect of global warming (Karl, 1995). Gershuvnov and Barnett (1998) recently investigated the relationship of ENSO to temperature and precipitation extremes over the United States. It is possible that there are effects of ENSO on the distribution that are not reflected in changes in the extremes. Also, because Gershuvnov and Barnett binned all the El Niño and La Niña events together, it is possible that their extreme value statistics are dominated by shifts of the means during El Niño or La Niña, and thus the effects of interannual variability. While the effect on absolute temperature extremes during ENSO is of course extremely important, it is possible that any interannual variability may mask some of the effects on intraseasonal variability, and it is this we plan to investigate.

2. Data

The primary dataset in this study is the NCEP/NCAR Reanalysis for 1958-1998. A description of the NCEP Reanalysis datasets can be found in Kalnay et al (1996). Air temperature on a 2.5x2.5 latitude-longitude grid on 0.995 sigma (normalized pressure) surface was used as a proxy of surface air temperature. In the reanalysis, air temperature has been declared a type “A” variable that is not strongly affected by the physics of the assimilating model. Daily values were calculated by averaging the 0z,6z,12z and 18z analyses. Results were compared against those obtained from the United States Historical Climatological Network dataset (USHCN) (Easterling, 1996) of daily station observations from 1900-1997. The stations in this dataset were chosen for their almost comprehensive time coverage and because they were less affected by urban heat island effects. They only cover a portion of the United States, so a complete comparison could not be made. However, they regionally confirm the results from the NCEP Reanalysis data and they also provide a way to check if any signals detected were consistent in another time period. Because the station data are not gridded and because daily values are defined as (Tmin+Tmax)/2, the variances in these station data are somewhat higher. However, since we are mainly concerned with the relative effects of ENSO on variance, these absolute differences do not pose a problem.

Our definition of an El Niño or La Niña event is based on the value of a combined SST/SOI index. The SST portion of the index is based on the Niña 3.4 region (5N-5S)(170-120W) of the Global sea-Ice Sea Surface Temperature (GISST) monthly mean dataset from 1958 to December 1998 (Rayner, 1995). The SOI timeseries is from Ropelewski and Jones (1987) that has been extended through 1998 using values from the Climate Prediction Center. To calculate the ENSO index, both timeseries were standardized separately for the 1871-1998 period. Then the standardized values for each of the variables were combined to produce one value for each month. The advantage of this index is that it is simple to compute and takes both the oceanic and atmospheric components of ENSO into account. A comparison of the ENSO events defined using this index with those from the Kalidas and Diaz (1989), the Center for Ocean-atmosphere Interaction Studies (COAPS), and the Climate Prediction Center (CPC), shows that the index captures most of the strong events with disagreement for some of the weaker ones (See Table A for the complete rankings). We will compare results using different definitions to assess their sensitivity to them.

3. Results

Fig. 1 shows the seasonal mean surface temperature response to El Niño (a) and La

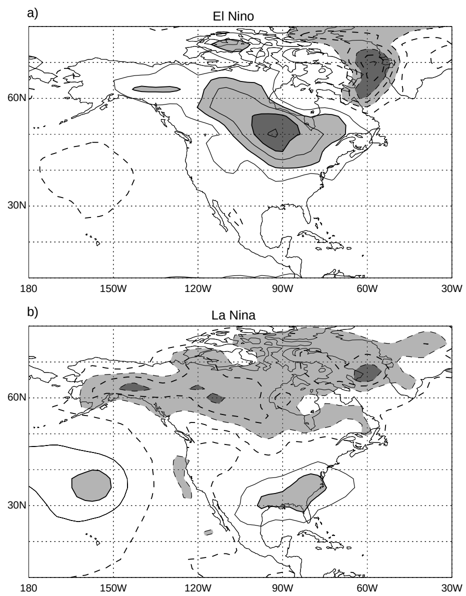

Fig. 1. Composite DJF seasonal mean surface temperature anomaly for a) 8 El Niño cases and b) 8 La Niña cases. Anomaly is based on the 1959-1998 timeperiod. Contour interval is.5˚C. Absolute values above 1˚C are shaded.

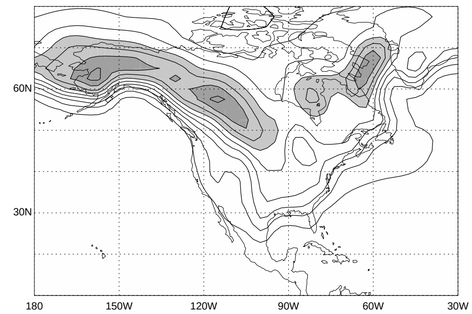

Fig. 2. Total intraseasonal variance for 1959-1998 winters (DJF). Contour interval is 10 ˚C^2. Absolute values above 60˚C^2 are shaded.

Niña (b). The figure shows the temperature anomalies averaged over 8 El Niño and 8 La Niña events during 1959-1998. Anomalies are defined as deviations from the 40 year mean. These maps are typical of the results of other studies in which El Niño winter is characterized by warm temperatures in the northwest U.S. extending eastward across Canada and cold temperatures in the extreme southern U.S. and Florida. La Niñas are characterized by cold temperatures across Canada, warm temperatures in Florida and cold temperatures in the Caribbean.

We next examined the behavior of the intraseasonal variance over the same timeperiod and for the same set of ENSO events. Variance was calculated by computing a mean and standard deviation for each season separately. Treating each year separately, rather than pooling all years, effectively removes the interannual variability. In regions where the seasonal mean response during ENSO varies greatly from event to event, the two methods will yield different results. Fig. 2 shows the average intraseasonal variance for the entire 40-year record. Most of the variance is over land with the highest values over northern Canada and generally decreasing southward, especially along the coasts and over the ocean. The high values over Alaska extend down along the east crest of the Rockies, and are presumably associated with stormtracks.

Fig. 3 shows maps of the El Niño (a) and La Niña (b) intraseasonal wintertime variances averaged over the eight strongest El Niño and La Niña events as determined by our ENSO index. The values shown have been normalized by the climatological variance. Results were also calculated relative to the “neutral” years defined as the remaining 24 non-ENSO years,

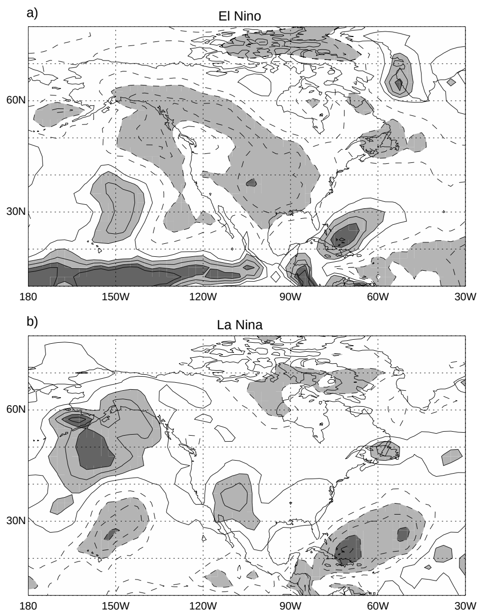

Fig. 3. Ratio of the composite intraseasonal surface temperature variance obtained for a) 8 El Niño cases and b) 8 La Niña cases to the climatological intraseasonal variance (1959-1998).Contour interval is 0.15. Values above 1.16 and below 0.84 are shaded.

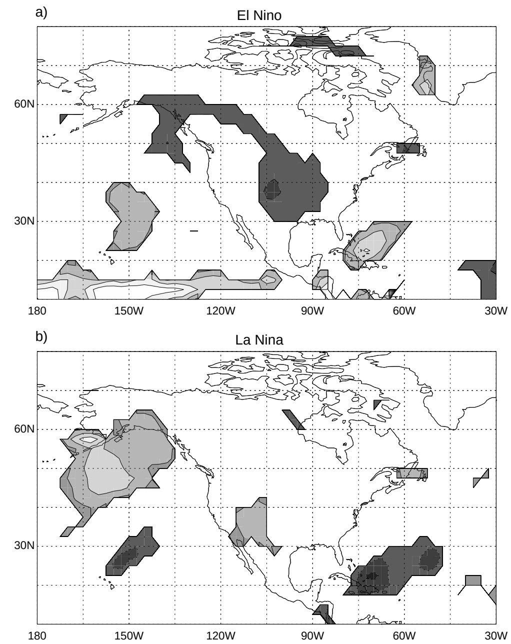

Fig. 4. Regions that had significant ratios of intraseasonal variance compared to climatology at the 90% level as determined from Monte Carlo tests for a)8 composite La Niña events b) 8 composite El Niño events. Contour interval is 0.10. Values above 1.10 and below 0.90 are shaded.

with little difference from those shown. For La Niña there is strong indication of an increase of variance southeast from Alaska, with the main axis along the east side of the Rockies extending south into northern Mexico. There are also increases off the south coast of Alaska and Labrador and a decrease near Cuba. The corresponding El Niño plot shows regions of decreased variance in the United States (especially in the south) and off the coast of Alaska with increased variance near Cuba. To assess the statistical significance of these results, Monte Carlo tests were performed using data from all 40 years. Sets of eight years (with replacement) were selected at random and the average intraseasonal variance was calculated. Regions where the El Niño and La Niña vari-

is in general opposite for El Niño and La Niña over the region, we also calculated the ratio of the La Niña variance to the El Niño variance (Fig. 5). Ratios are quite high (approaching 200%), especially over the U.S.,east and south of the Rockies, over the Caribbean and over the coast of Alaska. Since there are relatively few

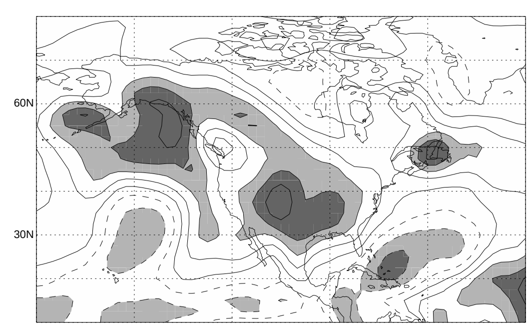

Fig 5

years in the composites, it is possible that the sampling affects the results. One way to assess this is to calculate the percentage of the 16 El Niño and La Niña events that had an increase of variance compared to climatology during La Niña and a decrease during El Niño. By chance, we would expect the percentage to be 50%. The results shown in Fig. 6 indicate that the actual percentages are quite high, with 94% (or 15 out of 16 years) over the southwestern U.S. Similarly there are regions like the Caribbean, where most years show higher variance during El Niño and lower variance during La Niña (<20%). This shows that there is a consistent intraseasonal variance response during most individual ENSO years in regions with strong signals.

Given what appears to be a strong, symmetric effect of ENSO on the variance, one may ask what features of the distribution are associated with these changes. Potentially, increased variance could be associated with greater temperature ranges than "normal" (i.e. with changes in kurtosis), greater deviations in one direction (i.e. changes in skewness), changes in both, or changes in neither. Fig. 7 shows the PDF of the daily temperature based on all 40 years for a gridbox in the southwestern US (255E,37.5N) that has a strong symmetric intraseasonal variance signal. The temperature distribution is approximately normal with a mean of 0.0, a median of 0.43 and a skewness of -0.48. The

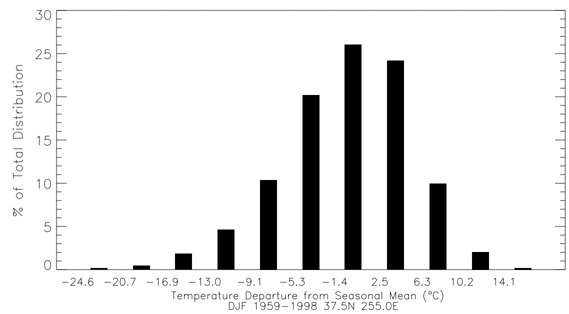

Fig. 7. The PDF of DJF surface temperature for all 40 years of surface temperature for the gridbox 255E,37.5 N. The seasonal mean is removed separately for each season.

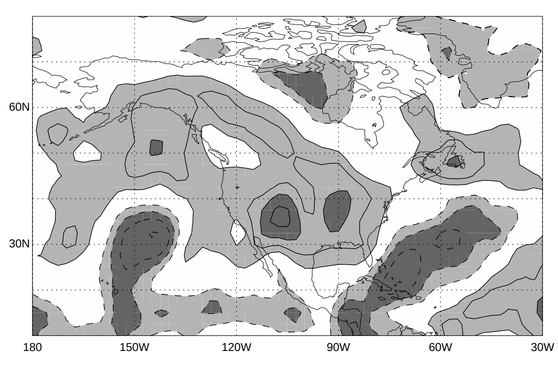

Fig. 6. Percentage of 16 total El Niño and La Niña years where the wintertime La Niña intraseasonal temperature variance was greater than zero and the El Niño intraseasonal variance was less than zero indicating a symmetrical effect. Contour interval is 10%. Values below 40% and above 60% are shaded.

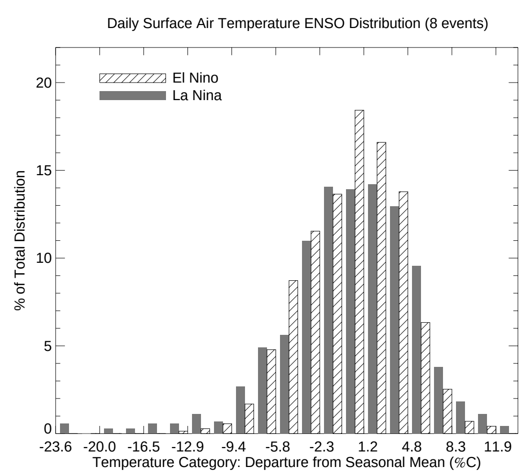

Fig. 8 The PDF of DJF surface temperature for the 8 El Niño events and 8 La Niña events for the gridbox 255E,37.5N Anomalies were calculated by removing the seasonal mean for each winter separately.

PDF’s for El Niño and La Niña are shown in Fig 8. The La Niña distribution, indicated by the dark bars, is more negatively skewed (skewness= -0.87) and has an extended range at both the high and low ends, compared to the El Niño distribution shown with the light bars. Fig. 9

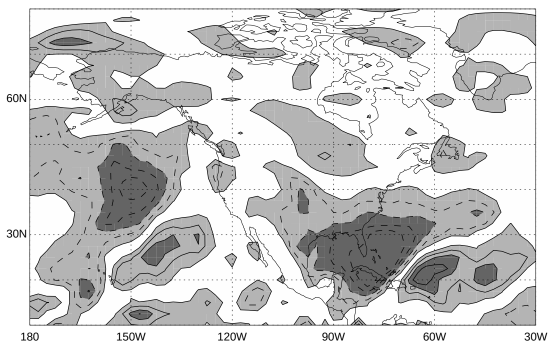

Fig. 9. Average skewness of wintertime daily surface temperatures for the 8 La Niña events minus the 8 El Niño events. Skewness was calculated for each year separately and then averaged Contour interval is 0.15C. Absolute values above 0.15 are shaded

shows the skewness difference for the entire region between La Niña and El Niño. Except over the Caribbean where the skewness seems to be in the right location to explain the increased variance, the plot does not correspond well with Figs. 3 or 5, especially over regions where the variance signal is large.

We also examined the range of daily temperatures within each season. To do this, we ranked all the temperature values during each season for each gridpoint and calculated the 10% and the 90% values. The difference in the average ranges for La Niña minus El Niño (90% value-10% value standardized by the climatological variance at each gridpoint) is shown in

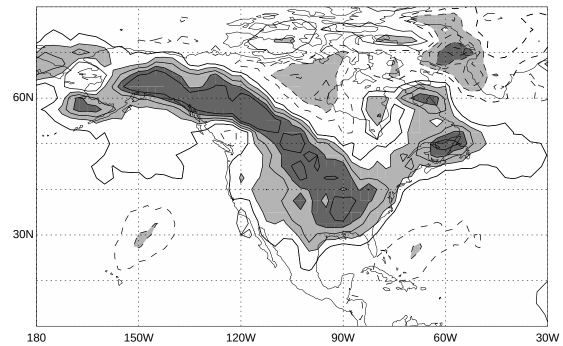

Fig. 10. Seasonal surface temperature range for the 8 composite La Niña events minus the range of the 8 El Niño events. Range is calculated by computing the 10% and 90% value for each season and then subtracting the 10% value from the 90% value.Contour interval is 0.75˚C. Absolute values above 1.50˚C

Fig. 10. The plot looks very similar to the variance plots of Figs. 3 and 5, especially over the United States. Note that the increased temperature range during La Niña compared to El Niño could be caused by an increase in the high range

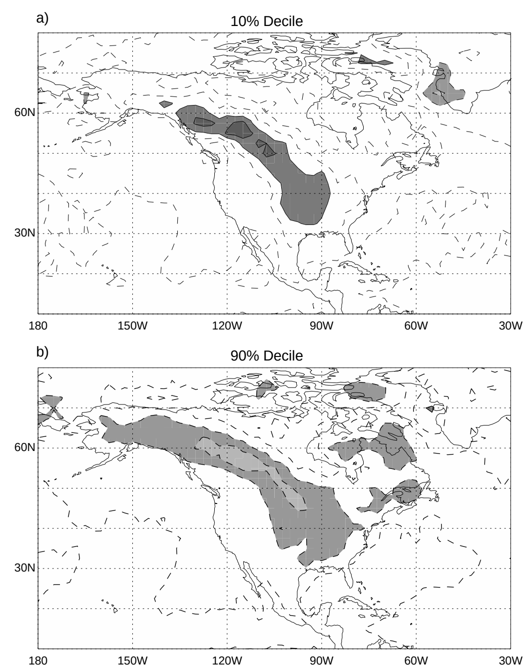

Fig. 11. a) 10% temperature value minus climatological 10% temperature value and b) 90% temperature value minus 90% climatological value for the eight composite El Niño cases. Contour interval is 0.75˚C. Absolute values above 1.50˚C are shaded.

for La Niña compared to El Niño and a decrease in the low range; Or, by a decrease in one or both ends of the range for El Niño. Fig. 11 shows the difference between El Niño and climatology for the a) lower 10% value and b) upper 90% value. Both ranges are contracted relative to climatology. La Niña results (not shown) have a much smaller increase in range at both the high and low ends

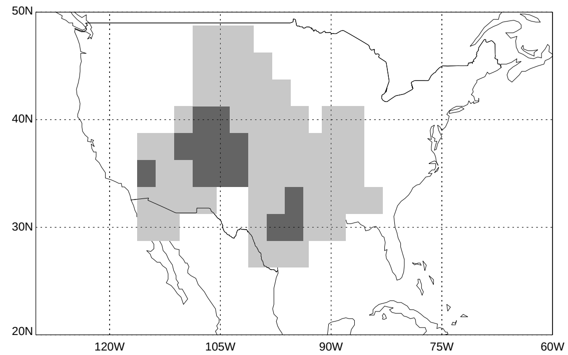

Fig. 12. Ratio of the composite surface temperature intraseasonal variance obtained from 8 La Niña events divided by the variance of the 8 El Niño events for the USHCN data, 1958-1997. Values above 1.30 are shaded; values below 0.70 are hatched.

4. Robustness of results

Monte Carlo tests show that the altered intraseasonal variances during El Niño and La Niña are significant in several regions. However, these results may be affected by several factors including differing definitions of El Niño/La Niña, choice of the dataset, and the time period under investigation. Since it is rare to find consistent definitions of El Niño or La Niña years, we calculated the ratio of the La Niña to El Niña variances using different ENSO definitions. These included a) the 4 strongest events based on our index, b) SOI alone, c) Niña 3.4 SST alone, d) a multivariate index, and e) our index, for 8 events. For the 255E,37.5N gridpoint located in the Southwestern US, where the ratio of the La Niña to El Niño variance was greater than 1, our estimates by these methods were a)1.80 b) 1.33 c) 1.64 d) 1.54 and e) 1.80, respectively. For the gridpoint 295E,25N, a region where the ratio was less than 1, our estimates were a) 0.58 b) 0.53) c) 0.57 d) 0.55 and e) 0.55. Thus the actual magnitude of the changes to the intraseasonal variance is open to uncertainty but their sign is not.

To address the possibility that the results were dataset dependent, we compared the NCEP results to those from the USHCN data for 1957-1997. While the intraseasonal variances in the station data were generally higher (up to 75% more), the ratio of variances was similar in magnitude with the major signals in similar locations (Fig. 12). Finally, to see how consistent our results were over time, we exam-

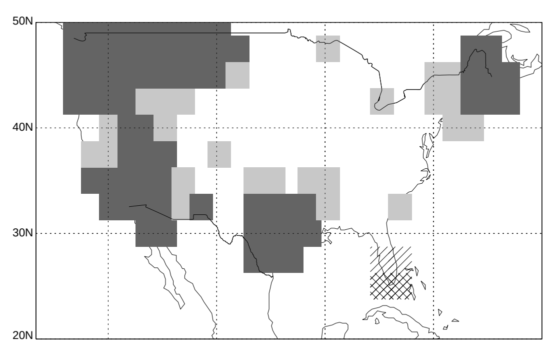

Fig. 13. Ratio of the composite surface temperature intraseasonal variance obtained from 8 La Niña events divided by 8 El Niño events for the USHCN data,1918-1957. Values above 1.1 are shaded; values below 0.90 are hatched

ined the 1918-1957 period, using our same ENSO index to define El Niño and La Niña events. Except over the Northwest U.S., the ratio of the La Niña intraseasonal variance to El Niño (Fig. 13) was similar with increases over the west and the extreme northeast and decreases in the extreme southeast However, the ratios were not as high and the difference in the ranges (not shown) were not as pronounced as in the 1959-1998 period.

5. Discussion

There is a significant relationship between ENSO events and wintertime intraseasonal temperature variance over the Pacific North American region, and this effect is reasonably consistent with respect to choice of dataset and definition of ENSO. These results are also consistent with studies of the variations in location and incidence of blocking over the North Pacific. For example, Mullen (1989) showed that during El Niño, blocking tends to occur preferentially over the west coast of North America, while during La Niña, it is suppressed over the Aleutian Islands. This is reflected in decreased cyclone activity over the western US (Noel, 1998) and less frequent excursions of cold and warm air during El Niño.

Practical consequences of increased intraseasonal variability include effects on both extreme values and on absolute values. Gershovnov and Barnett (1998) examined the effect of ENSO on the 5% extremes of surface temperature over the US. They showed that El Niño events tended to be associated with decreased high temperature extremes and increased low temperatures extremes over much of the US. For La Niña, the signals were less consistent. Absolute values are of great practical importance as well. For example, the energy industry uses estimates of “heating degree days” and “cooling degree days” to assess how much energy is required to heat (or cool) a building to comfortable levels. Heating degree days are defined for each day as 0 if the observed temperature is above 65F, and as 65F minus the observed temperature if the temperatures is below 65F. That is

$$\text{HDD}= 65\text{F}-T \text{ if } T<65\text{F}$$

$$\text{HDD}= 0 \text{ if } T >=65\text{F}$$

Cooling degrees are defined similarly but for temperatures above 65F and estimate the energy involved in cooling to 65F. The total number of heating or cooling degree days in a season is of interest. Both measures are affected by changes of mean and a change in the variance. Note that at locations at which the daily temperature is always above or below 65F throughout the season, the difference between heating (cooling) degree days between El Niño and La Niña would simply reflect the difference in the seasonal means. At all other locations, any other change in the distribution will also have an effect on the heating or cooling degree days.

Fig. 14a shows an example of two distributions with the same mean (0.0) but with distribution B

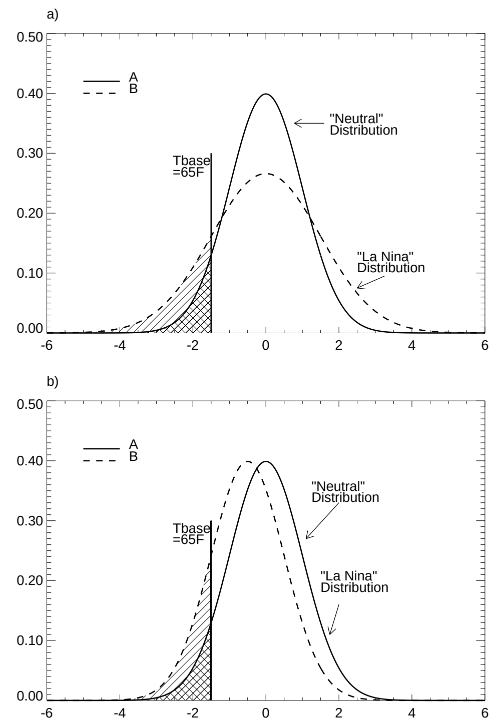

Fig. 14. "Heating Degree Days" calculated with reference to a base temperature of -1.5 for a) a normal distribution (0 mean, 1.0 std.) compared to a distribution with the same mean but a std of 1.4 b) a normal distribution (0 mean, 1.0 std) compared to a distribution with the same variance but a mean of -0.4.Degree days are represented by the area that is shaded under the curves.

(dashed) having greater variance than distribution A (solid). In this case, the number of heating degree days, which is proportional to the area shaded under B, is greater than that under A. Fig b) shows the heating degree days for the case where there is a mean shift but no change of variance. Again, the number of heating degree days is greater in B than in A. Note that in the case of a) where only the variance increases, B will have more heating degree days as long as the base temperature value (=65F) is less than the mean of the two distributions. If the base value is above the mean, it will have less. For case b) where the only the mean shifts to the left, B will always have more heating degree days than A.

When we consider the difference in heating degree days between La Niña and El Niño, it will tend to resemble the difference in the means. This is because as long as the seasonal mean temperatures are above (or below) the base value, the difference in heating degree days will be a monotonic function of the difference in the means. Where the mean temperatures straddle the base value this isn't necessarily the case. In practice, however, the variance is small compared to the mean so the heating degree day differences resemble differences of the mean.

In middle latitudes, the effect on absolute values can be seen more clearly when we plot the number of days below 32F for La Niña minus El Niño conditions. Here, seasonal mean

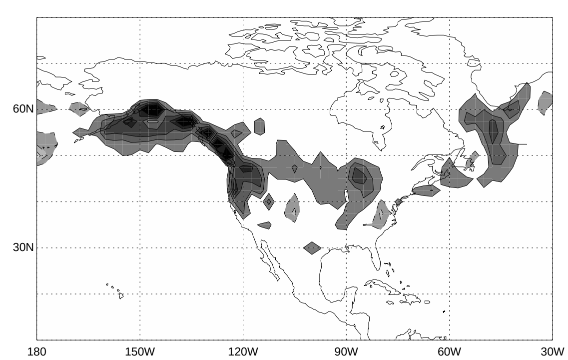

Fig. 15. Number of days with daily average surface temperature less than 32F for La Niña minus the number of days during El Niño. Based on the NCEP DJF temperatures for 1959-1998.Contour interval is 2 days. Values above 2 are shaded.

values are closer to the base temperature of 32F in regions where there are high variance differences. Where daily temperatures are always above or below 32F, the difference in the number of “freezing days” between El Niño and La Niña will be zero. The effect of the mean difference is most evident in Fig. 15 in the northwest where colder temperatures during La Niña are associated with more days below 32F. However, the differences in variance and skewness also have an impact, especially during La Niña, with more freezing days in the Southeast U.S. and Central California. The California change is especially intriguing, since it occurs despite a higher seasonal temperature mean during La Niña. All of these results demonstrate the importance of studying not just the mean response to ENSO but also the effect on the distribution.

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Table 1
Combined SOI/Niña 3.4 ENSO index, ranked from lowest value (La Niña) to highest (El Niño)

Year	Index Value
1974	-1.81
1976	-1.56
1989	-1.31
1971	-1.26
1962	-0.53
1967	-0.49
1972	-0.42
1985	-0.40
1997	-0.40
1968	-0.40
1963	-0.38
1975	-0.29
1996	-0.25
1984	-0.18
1965	-0.12
1960	-0.10
1961	-0.08
1986	-0.07
1982	-0.06
1981	0.05
1979	0.08
1994	0.23
1991	0.36
1980	0.39
1977	0.40
1990	0.63
1988	0.66
1993	0.72
1970	0.74
1964	0.79
1959	0.83
1966	0.92
1969	1.00
1995	1.03
1978	1.17
1987	1.17
1973	1.38
1992	1.83
1998	2.39
1983	2.70

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